

# **Towards Sustainable Wastewater Reuse in the Middle East and North Africa**

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## Scholarly Abstract

Water has a precious value and each drop must be accounted-for in water scarce regions such as the Middle East and North Africa. Therefore, wastewater has to be reclassified as a renewable water resource rather than waste. This helps in augmenting water availability, and at the same time in preventing environmental pollution. Utilization of this resource requires collection, treatment, and use of all generated wastewater. Although reuse of wastewater is recognized in most water-scarce countries, the reuse of wastewater is still very low. This paper analyzes the major components of a sustainable wastewater reuse scheme. It also reviews the different methods that are frequently used to quantify and report progress and achievements in wastewater reuse. The paper also introduces an alternative yardstick named by the author as the *Wastewater Reuse Index (WRI)* that has a value between 0-100; *WRI* is calculated by dividing the amounts of wastewater being actually reused by the total amounts of wastewater generated at country level. *WRI* enables water resource managers and policy-makers to put a figure on the gap between achievements at different junctures. Moreover, *WRI* recognizes water saving efforts such as low water consumption and reducing losses; thus, highlights the way forward for improving the reuse efficiency as an integral part of water resources management. The paper highlights the major barriers to extensive reuse of the reclaimed wastewater in the MNEA countries.

Keywords: MENA region; wastewater; sustainable reuse; utilization

## **Authors' Note**

Wastewater reclamation and reuse is well recognized for its ability to mitigate water shortage which is a major threat to sustainable development and political stability in the Middle East and North Africa region. Substantial efforts have been made to make better utilization of wastewater as a non-conventional water resource. These efforts have been undermined by the lack of vision towards integration of wastewater reuse within water resources management. This paper helps policy-makers and experts in efficient planning of national water resources, especially wastewater management and extensive reuse.

Keywords: MENA; wastewater; sustainable development; utilization.

# Towards Sustainable Wastewater Reuse in the Middle East and North Africa

## Introduction

Water has a precious value and each drop must be accounted-for in water scarce regions such as the Middle East and North Africa region (MENA). The region dwells five percent of the world population and has less than one percent world's available water. Water scarcity is a major threat for food security and political stability in the region. Much of the water crisis is caused by the way water is used. More than 89% of MENA's withdrawn water is allocated to agriculture and only 11% to municipal and industrial uses. Alleviation of the water scarcity implies reallocation of freshwater from agricultural to domestic and industrial uses. According to the World Bank<sup>1</sup>, a reduction in agricultural water use by 15% would double the water available to households and industry in the region. This would reduce irrigated agriculture at the time many countries aim to expand it due to food security reasons. Besides, the MENA countries avoid inter-sector water transfer, mainly due to internal political considerations<sup>2</sup>; for example, farmers in the Jordan Valley have strong influence on the Jordanian policy makers due to the clan-type of social structure. In search for additional water supplies, the regional water experts and aid agencies have recognized reclaimed wastewater as a valuable non-conventional water resource.

Nevertheless, substantial amounts of water that originate from different human activities used to be considered as waste due to the deterioration of water quality and due to psychological considerations. In addition to water scarcity, the wide enough range of technologies that now exist to purify this wastewater to acceptable levels<sup>3</sup> increased the chances for wastewater to be reclassified as a renewable water resource rather than waste<sup>4, 5, 6</sup>. In many countries such as

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<sup>1</sup> World Bank. (2000). Wastewater treatment and reuse in the Middle East and North Africa Region (MENA). World Bank, Washington, DC.

<sup>2</sup> Saghir, J., Schiffler, M., and Woldu, M. (2000). Urban water and sanitation in the Middle East and North Africa Region: The way forward. The World Bank, MENA, Infrastructure Development Group.

<sup>3</sup> Kalbermatten Associates, Inc. (1999). Study to identify gaps, issues and constraints in urban environmental sanitation. Report No. 1: Preliminary identification of gaps. A study funded by the Department for International Development, United Kingdom, and executed by the UNDP/World Bank Water and Sanitation Program Washington, D.C., U.S.A.

<sup>4</sup> Asano, T. and Levine, A. (1996). Wastewater reclamation, recycling and reuse: past, present and future. *Wat. Sci. Tech.*, **33**(10-11): 1-14.

<sup>5</sup> Eden, R. (1996). Wastewater reuse - limitations and possibilities. *Desalination*, **106**: 335-338.

Israel, Jordan, and Tunisia, wastewater is becoming a preferred unconventional source of water<sup>7</sup>,<sup>8</sup>,<sup>9</sup>,<sup>10</sup>,<sup>11</sup>,<sup>12</sup>, whose supply is increasing, because of population growth, and its costs are relatively low<sup>13</sup>,<sup>14</sup>,<sup>15</sup>. Yet in the MENA countries, substantial proportions of wastewater are discharged without or poorly treated. In other words, wastewater utilization in the MENA region is very low despite water scarcity and strong demand for water supply augmentation.

Oron *et al.*<sup>16</sup> identified two basic requirements for utilization of wastewater as a solution for water shortage problems whilst minimizing the health and environmental risks: (i) the need for comprehensive wastewater collection systems, and (ii) the need for well-operated wastewater treatment facilities. Mills and Asano<sup>17</sup> rightly emphasized a third requirement, namely securing users for the treated effluents. Thus, to maximize the contribution of wastewater reuse to the total water availability, the generated wastewater needs to be collected, treated, and used: three “pillars” of wastewater utilization. In order to better understand why reuse is still limited in the MENA countries, reclaimed wastewater is recognized as a commodity whose market comprises: (i) a supply side, which refers to the production, collection, and treatment of wastewater, (ii) a demand side, which refers to the use of the reclaimed wastewater, and (iii) market control and monitoring, which refers to the regulatory and institutional framework. In the MENA countries, the reclaimed-wastewater market is unbalanced; i.e., growing supply – which is demonstrated by

<sup>6</sup> Asano, T., Maeda, M., and Takaki, M. (1996). Wastewater reclamation and reuse in Japan: overview and implementation examples. *Wat. Sci. Tech.*, **34**(11): 219-226.

<sup>7</sup> Otterphol, R., Albold, A. and Oldenburg, M. (1999). Source control in urban sanitation and waste management: Ten systems with reuse of resources. *Wat. Sci. Tech.*, **39**(5): 153-160.

<sup>8</sup> Mubarak, J. (1998). Middle East and North Africa: Development policy in view of a narrow agricultural natural resource base. *World Development*, **26**(5): 877-895.

<sup>9</sup> Angelakis, A., Marecos, M., Bontoux, L. and Asano, T. (1999). The status of wastewater reuse practice in the Mediterranean basin: Need for guidelines. *Wat. Res.*, **33**(10): 2201-2217.

<sup>10</sup> Bahri, A. (1999). Agricultural reuse of wastewater and global water management. *Wat.Sci.Tech.*, **40**(4-5):339-346.

<sup>11</sup> Hussain, G. and Al-Saati, A. (1999). Wastewater quality and its reuse in agriculture in Saudi Arabia. *Desalination*, **123**: 241-251.

<sup>12</sup> Faruqi, N. (2000). Wastewater treatment and reuse for food and water security. IDRC. Ottawa, Canada. [www.idrc.ca/waterdemand/SpecialPapers\\_e.html](http://www.idrc.ca/waterdemand/SpecialPapers_e.html).

<sup>13</sup> Asano, T. and Levine, A. (1995). Wastewater reuse: a valuable link in water resources management. *Water Reuse, WQI*, No. 4.

<sup>14</sup> Haruvy, N. (1997). Agricultural reuse of wastewater: nation-wide cost benefit analysis. *Agricultural, Ecosystem and Environment*, **66**: 113-119.

<sup>15</sup> Haruvy, N. (1998). Wastewater reuse - regional and economic considerations. *Resources, Conservation and Recycling*, **23**: 57–66.

<sup>16</sup> Oron, G., Campos, C., Gillerman, L., and Salgot, M. (1999). Wastewater treatment and reuse for agricultural irrigation in small communities. *Agricultural Water Management*, **38**: 223-234.

<sup>17</sup> Mills, R. and Asano, T. (1996). A retrospective assessment of water reclamation projects. *Wat. Sci. Tech.*, **33**(10-11): 59-70.

the increasing sewerage coverage and number of wastewater treatment plants – and stagnant demand – which is demonstrated by the substantial proportions of treated effluents that are not used but discharged into the receiving water bodies. Balancing the reclaimed-wastewater market (i.e., reducing the gap between supply and demand) implies increasing the rates of collection, treatment, and reuse close to the rate of wastewater generation.

Water scarcity has made wastewater reuse more prominent in technical and policy literature as well as in national and international professional meetings. Several indicators are being used to quantify achievements and progress in wastewater reuse. However, until now no standard yardstick exists to measure overall reuse efficiency at a country's level that meets the following criteria: (i) considers all wastewater production (collected and uncollected), (ii) recognizes the importance of each of these subsequent steps of production, collection, treatment, and use of the wastewater, (iii) allows comparisons within and among countries, and (iv) accounts for wastewater that is utilized through on-site and low cost means. The currently used yardsticks are based only on the amounts of urban wastewater and omit to take account of the wastewater that does not pass through conventional collection and treatment.

To quantify achievements in wastewater reuse, the commonly used indicators are: (i) flow rate (million cubic meters per year), (ii) as percentage of wastewater treated, (iii) as percentage of municipal sewage produced, (iv) as percentage of total tap water supplied, (v) as percentage of urban water supply, (vi) as percentage of agricultural water supply, (vii) as percentage of total area irrigated, and (viii) as area of land irrigated with reclaimed wastewater. For example, reuse efficiency in Israel is assessed in Freidler<sup>18</sup> as 65% of the municipal sewage production, in Freidler<sup>19</sup> as 80% of all irrigation water in the Jeezrael Valley, in Shelef and Azov<sup>20</sup> as 24.4% of the total water supply, in Idelovitch<sup>21</sup> as 250 million cubic meter per year, as 60% of the total urban water supply, as 83% of the treated effluent, and as 20% of the irrigated

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<sup>18</sup> Freidler, E. (2001). Water reuse – an integral part of water resources management: Israel as a case study. *Water Policy*, **3**: 29-39.

<sup>19</sup> Freidler, E. (1999). The Jeezrael Valley project for wastewater reclamation and reuse, Israel. *Wat. Sci. Tech.*, **40**(4-5): 347-354.

<sup>20</sup> Shelef, G. and Azov, A. (1996). The coming era of intensive wastewater reuse in the Mediterranean region. *Wat. Sci. Tech.*, **33**(10-11): 115-125.

<sup>21</sup> Idelovitch, E. (2001). Wastewater reclamation for irrigation: The Dan Region Project in Israel. Prepared for the World Bank, Washington DC.

area. Bahri and Brissaud <sup>22</sup> assessed reuse efficiency in Tunisia as 6,500 ha of irrigated land and as 15% of the available treated wastewater. Other country examples are shown in Table 1. These indicators are useful but inadequate to capture the potential for and achievements in efficiency improvement.

**Table 1: Wastewater reuse rates for agricultural irrigation**<sup>23, 24</sup>.

<i>Location</i>	<i>Volume reused (million m<sup>3</sup>/y)</i>	<i>As of total sewage (%)</i>	<i>As of total irrigation (%)</i>
<i>Germany</i>	100	3	10
<i>China</i>	10,000	27	-
<i>Mexico</i>	1,500	100	80
<i>Santiago, Chili</i>	190	100	70

In the above cases also, the “potential” for reuse refers to the amounts of urban wastewater that is being collected and treated through conventional means and possibly would be added to the national water balance <sup>9, 11, 25</sup>. The author defines the “potential” for reuse as the actual hydraulic capacity of the wastewater resource – i.e., total amount of wastewater production (urban and rural) – combined with the existing enabling environment – i.e., technical, financial, regulatory, institutional, and socio-cultural capacity – to utilize this resource.

This paper aims at: (i) identifying the components of sustainable wastewater utilization, (ii) analyzing the indicators frequently used for quantifying achievements in wastewater reuse, and (iii) introducing a yardstick called *Wastewater Reuse Index (WRI)*.

## **Wastewater utilization**

### *Wastewater generation*

The total amount of wastewater generation is the hydraulic capacity of the wastewater resource, which can be quantified in three different ways:

- *Measuring water supply.* The generated amounts of wastewater can be derived from the total water supply for domestic, industrial, and commercial uses. This method is not favored since it is difficult to make countrywide estimates for the amounts of water supplied from

<sup>22</sup> Bahri, A. and Brissaud, F. (1996). Wastewater reuse in Tunisia: Assessing a national policy. *Wat. Sci. Tech.*, **33**(10-11): 87-94.

<sup>23</sup> Khouri, N., Kalbermatten J., and Bartone, C. (1994). The reuse of wastewater in agriculture: A guide for planners. UNDP - World Bank Water and Sanitation Program. Washington, DC., The World Bank.

<sup>24</sup> Al-Hamdi, M. (2000). Competition for scarce groundwater in Sana'a plain, Yemen: a study on the incentives system for urban and agricultural water use. PhD thesis, IHE-Delft, The Netherlands.

<sup>25</sup> Angelakis, A. and Bontoux, L. (2001). Wastewater reclamation and reuse in Eureau countries. *Water Policy*, **3**: 47-59.

alternative non-public sources such as private water vendors, rainwater harvesting, and springs. Moreover, the unaccounted-for water in the supply systems adds uncertainty.

- *Measuring wastewater flows.* This method measures only the metered wastewater flows from sewerred communities. The amounts of wastewater generated from communities using cesspits and septic tanks must to be estimated and accounted.
- *Measuring water consumption.* This method quantifies the amount of wastewater generated from domestic, commercial, and industrial water uses based on the average per capita water consumption, taking into consideration that not all the consumed water enters the sanitation system. This technique is most recommended since it allows easy calculation and takes into consideration the water saving efforts. Water saving means less per capita water consumption, less wastewater generation, and therefore lower costs. Table 2 shows estimates for domestic wastewater production and collection in some MENA countries.

**Table 2: Domestic wastewater production and collection rates in some MENA countries.**

Country	Population (thousands)			Water consumption *			Wastewater collection					
	Urban	Rural	Total	Urban	Rural	Total	(% of population) **			(million m <sup>3</sup> /yr) ***		
Algeria	18,969	12,502	31,471	831	319	1,150	90	47	73	598	120	718
Egypt	30,954	37,515	68,469	1,356	959	2,314	98	91	94	1,063	698	1,761
Iraq	17,756	5,359	23,115	778	137	915	93	31	79	579	34	613
Jordan	4,948	1,721	6,669	217	44	261	100	98	99	173	35	208
Lebanon	2,945	337	3,282	129	9	138	100	87	99	103	6	109
Libya	4,911	693	5,604	215	18	233	97	96	97	167	14	181
Oman	2,135	407	2,542	94	10	104	98	61	92	73	5	78
Saudi Arabia	18,526	3,081	21,607	811	79	890	100	100	100	649	63	712
Syria	8,783	7,342	16,125	385	188	572	98	81	90	302	122	423
Tunisia	6,281	3,305	9,586	275	84	360	97	48	80	214	32	246
Yemen	4,476	13,636	18,112	196	348	544	87	31	45	136	86	223

\* Estimated based on 120 l/c/d for urban and 70 l/c/d for rural; it does not include commercial and industrial water.

\*\* Sewerage and on-site collection systems.

\*\*\* Assumed that 80% of the water consumption is collected as wastewater.

### *Wastewater collection*

Collection here refers to the wastewater produced across the country that enters the sewerage system or the on-site disposal systems; to a large extent, it is approximated by figures of sanitation coverage. In most MENA countries, there is a continuing increase in the collection rate of wastewater, especially through sewerage networks that are gradually expanding. This is driven mainly because wastewater collection is considered an urban necessity that serves health and



environmental purposes<sup>26, 27</sup>. The estimates for total collection rates of wastewater are very high in many MENA countries (Table 2); this includes conventional sewerage and on-site disposal such as cesspits and septic tanks. Thus, it can be assumed that sanitation coverage and wastewater collection are not the limiting factors for wastewater utilization in most of the region.

### *Wastewater treatment*

Wastewater collected from communities and industries ultimately returns to receiving water bodies or to the land. Wastewater contains organic materials whose decomposition can lead to the production of large quantities of malodorous gases. In addition, untreated wastewater usually contains numerous disease-causing microorganisms that dwell in the human intestinal tract. Wastewater also contains nutrients, which can stimulate excessive growth of aquatic plants and algae (eutrophication), and it may contain toxic compounds<sup>28</sup>. These contaminants have to be removed or reduced to a safe and environmentally sound level for environmental protection purposes in order that the water course can retain its utility (for fishing, bathing, etc.) downstream. In addition, if the wastewater can be treated to a high enough quality standard, it also provides for a badly needed non-conventional water resource. The level of required wastewater treatment is case-specific and directly related to the quality requirements associated with the end-use<sup>4</sup>. The typical wastewater end-uses are: (i) discharge into the sea (with minimum disturbance of the existing ecosystem), (ii) discharge into surface water, (iii) discharge into groundwater aquifers, (iv) restricted agricultural irrigation, (v) unrestricted agricultural irrigation, (vi) aquaculture, (vii) non-potable domestic use, (viii) potable water use, and (ix) industrial use. In all these cases, wastewater treatment is a requisite.

Conventional wastewater treatment, typically, consists of a combination of physical, chemical, and biological processes and operations to remove solids, organic matter and, sometimes, nutrients from wastewater. General terms used to describe different degrees of treatment, in order of increasing treatment level, are preliminary, primary, secondary, and tertiary and/or advanced wastewater treatment. The conventional treatment systems tend to be

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<sup>26</sup> Bakir, H. (2000). Guiding principles and options for accelerated extension of wastewater management services to small communities in EMR countries. World Health Organization. Regional Office for the Eastern Mediterranean. Regional Center for Environmental Health Activities (CEHA). December 2000, Amman, Jordan.

<sup>27</sup> WHO. (2000). Global water and sanitation assessment 2000. Report.

<sup>28</sup> Metcalf and Eddy Inc. (1991). Wastewater engineering: Treatment, disposal, and reuse. McGraw-Hill International, Third Edition.

expensive at small scale. Therefore, in rural and peri-urban environments, wastewater can be treated in alternative, low-cost treatment systems such as septic tanks with attached sub-drainage irrigation pipes, up-flow anaerobic tanks and ponds followed by furrow or pumped irrigation, etc. However, these systems are beyond the scope of this study.

The frequently used systems for urban wastewater treatment in the MENA are activated sludge systems, trickling filters, and lagoons<sup>29, 30</sup>. In some countries, disinfection to remove pathogens sometimes follows the last treatment step.

### *Wastewater reuse*

The collected wastewater must be treated to adjust its quality to any of the following end-uses: (i) irrigation, (ii) artificial recharge, (iii) potable water supply, (iv) toilet flushing, and (v) industrial water supply. Reuse of wastewater has been practiced in many areas worldwide for thousands of years<sup>31</sup>. There are two strong economic incentives to reuse reclaimed wastewater: (i) augmentation in regions with water scarcity, and/or (ii) avoiding the cost of the deterioration of the water resources and the environment that would be polluted when receiving un- or partly treated wastewater.

As far as possible, the wastewater from rural and small communities should be reused as well. In those cases, on-site and low cost systems can provide for decentralized collection and treatment of the wastewater. However, in practice in most cases, cesspits and permeable septic tanks are used whose effluents infiltrate into the surrounding soil indiscriminately polluting groundwater, thus jeopardizing public health<sup>27</sup>. Although their effluent is often indirectly partially “reused”, this flow must not be accounted for as this practice is not sound. Likewise, direct or indirect irrigation with raw wastewater must not be accounted for as this practice is not in accordance with national and international sound reuse standards<sup>32, 33, 34</sup>.

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<sup>29</sup> Bahri, A. (1998). Fertilizing value and pollution load of reclaimed water in Tunisia. *Wat. Res.*, **32**(11): 3484-3489.

<sup>30</sup> Jamrah, A. (1999). Assessment of characteristics and biological treatment technologies of Jordanian wastewater. *Bioprocess Engineering*, **21**: 331-340.

<sup>31</sup> Mara, D. and Cairncross, S. (1989). Guidelines for the safe use of wastewater and excreta in agriculture and aquaculture: Measures for public health protection. WHO, Geneva.

<sup>32</sup> WHO. (1989). Health guidelines for use of wastewater in agriculture and aquaculture. Report of a WHO scientific group. Technical report series, no. 778. WHO, Geneva.

<sup>33</sup> Rowe, D. and Abdel-Magid, M. (1995). Handbook of wastewater reclamation and reuse. Lewis Publishers, USA.

<sup>34</sup> EPA. (1991). Alternative wastewater collection systems: Manual. US Environmental Protection Agency, U.S. Agency for International Development, Washington, DC. USA.

*Reuse for agricultural irrigation:* Since the beginning of the 1980s many countries have been using untreated or partially treated wastewater for agricultural irrigation<sup>25, 35</sup>. Treated wastewater is used for agricultural irrigation directly and indirectly. In direct reuse, the treated effluent is taken from the wastewater treatment plants (WWTPs) to the irrigation site. For example, part of the treated effluents in Tunisia is used to irrigate about 6,750 ha of orchards (citrus, grapes, olives, peaches, pears, apples, and pomegranate), fodder, cotton, cereals, golf courses and lawns. In indirect reuse, the treated effluent is discharged into surface water or groundwater aquifers. The effluents, thus, are deliberately blended with freshwater available in the wadis, dams, rivers, and aquifers and used, on purpose or not, by downstream farmers. In most cases it is used for unrestricted irrigation; reclaimed wastewater can be used for all crops even those consumed raw or uncooked. For example, most of the treated wastewater in Jordan is blended with freshwater from the King Talal Reservoir and used downstream in the Jordan Valley for unrestricted irrigation<sup>12, 36</sup>. In the Dan Region Project of Israel, more than 100 million cubic meters of treated wastewater are leached annually to the groundwater aquifer. Water is then pumped by production wells to the main conveyance system and to the distribution network to be used for unrestricted irrigation<sup>12, 20</sup>.

*Reuse for municipal uses:* Municipal wastewater reuse can be divided into three categories:

- i) *Direct potable reuse.* Wastewater is treated to a level that is acceptable for human consumption. Wastewater for direct potable use usually goes through two subsequent treatment processes, conventional and advanced. Despite the viability of the treatment technology to produce an acceptable drinking water quality from wastewater, it is unlikely that it will be widely adapted because of the high cost and low public acceptance.
- ii) *Indirect potable reuse.* It is very common and applied through the disposal of treated wastewater into surface or groundwater, which is used downstream as a potable water supply source. Many of the large cities and towns that are located along the major rivers and lakes depend on water from those water bodies for their domestic water supply.

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<sup>35</sup> Pescod, M. B. (1992). Wastewater treatment and use in agriculture. FAO irrigation and drainage paper no. 47. Food and Agriculture Organization of the United Nations, Rome, Italy.

<sup>36</sup> Shatanawi, M. and Fayyad, M. (1996). Effect of Khirbet As-Samra treated effluent on quality of irrigation water in the Central Jordan Valley. *Wat. Res.*, **30**(12): 2915-2920.

These water bodies at the same time receive treated and raw sewage from upstream cities and industries<sup>24, 29</sup>.

- iii) *Non-potable reuse*. This includes reuse of reclaimed wastewater for irrigation of landscape, greenbelts, golf courses, public parks, sport fields, in addition to fire fighting, and toilet flushing. The use of reclaimed wastewater for irrigation of landscape, public parks, sport fields, and recreational sites has become a widespread practice in Kuwait, United Arab Emirates, and Tunisia<sup>6, 37, 38, 39</sup>.

*Reuse for industrial and environmental uses*: The availability of well-treated wastewater at comparatively low cost and the scarcity of good-quality natural water are strong incentives for innovative reclamation projects. Reclaimed wastewater is ideal for many industries where processes do not require water of potable quality. Also, industries are often located near populated areas where centralized WWTPs already generate an available source of reclaimed wastewater. Wastewater reuse for industrial purposes is widely practiced in the world<sup>6, 35, 38</sup>. Reuse of reclaimed wastewater for environmental purposes is becoming a common practice in arid and semi-arid areas, especially in the form of artificial recharge in order to protect groundwater from seawater intrusion<sup>39, 40</sup>.

## Wastewater Reuse Index (WRI)

Despite the existence of the aforementioned indicators measuring wastewater reuse, an indicator with more potential is the *Wastewater Reuse Index (WRI)* which quantifies the total amount of wastewater being reused as percentage of the total hydraulic capacity of the total wastewater production. The *WRI* calculation depends on the following realities: (i) wastewater collection is subsequent to wastewater production, (ii) wastewater treatment is subsequent to wastewater collection, and (iii) wastewater reuse is subsequent to appropriate wastewater treatment. Accordingly, the WRI derivation steps are represented as follows:

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<sup>37</sup> Arar, A. (1991). Wastewater reuse for irrigation in Near East region. *Wat. Sci. Tech.*, **23**: 2127-2134.

<sup>38</sup> Maeda, M., Nakada, K., Kawamoto K., and Ikeda, M. (1996). Area-wide use of reclaimed water in Tokyo, Japan. *Wat. Sci. Tech.*, **33**(10-11): 51-57.

<sup>39</sup> Pettygrove, S. and Asano, T., eds. (1985). *Irrigation with reclaimed municipal wastewater: a guidance manual*. Chelsea, Mich., Lewis Publishers.

- Total amount of wastewater produced (G) from urban, rural, commercial, and industrial water users in the country depends on the population size, specific water consumption (l/c/d), and water losses, as in Eqn. 1:

$$G = f(\text{domestic, commercial, and industrial water consumption, water losses}) \quad (1)$$

- Total amount of wastewater collected (C) through sewerage and onsite systems is represented as percentage (x) of produced wastewater (G), as in Eqn. 2:

$$C = \frac{x.G}{100} \quad (2)$$

- Total amount of wastewater treated (T) through appropriate offsite and onsite systems is represented as percentage (y) of collected wastewater (C), as in Eqn. 3:

$$T = \frac{y.C}{100} \quad (3)$$

- Total amount of wastewater reused (R) through irrigation, groundwater recharge, industrial use, potable use, toilet flushing, and acceptable onsite reuse is represented as percentage (z) of treated wastewater (T), as in Eqn. 4:

$$R = \frac{z.T}{100} \quad (4)$$

- The Wastewater Reuse Index (WRI) is the percent ratio of total amount of wastewater reused (R) to total amount of wastewater produced (G), as in Eqns. 5 and 6:

$$WRI = f(R, G) \quad (5)$$

$$WRI = \frac{R}{G} \cdot 100 \quad (6)$$

- Substituting Eqn. 4 instead of R in Eqn. 6 gives WRI in terms of z, T, and G. Substituting Eqn. 3 instead of T gives WRI in terms of y, z, C, and G. Substituting Eqn. 2 instead of C gives WRI in terms of x, y, and z. These are shown in Eqns. 7 and 8:

$$WRI = \frac{z.T}{100.G} \cdot 100 = \frac{z.T}{G} = \frac{z.(y.C)}{100.G} = \frac{y.z.(x.G)}{G.10^4} = \frac{x.y.z}{10^4} \quad (7)$$

$$WRI = \frac{R}{G} \cdot 100 = \frac{x.y.z}{10^4}, \quad 0 \leq WRI \leq 100 \quad (8)$$

Where

$WRI$  = Wastewater Reuse Index (0-100)

$x$  = wastewater collection as percentage of total production,

$y$  = wastewater treatment as percentage of total collection,

$z$  = wastewater reuse as percentage of total treatment.

*WRI* can be used by water resource managers and policy makers to put a figure on the gap between achievements at different junctures. Moreover, *WRI* recognizes water saving efforts such as low water consumption and reducing losses; thus, highlights the way forward for improving the reuse efficiency. Figure 3 provides *WRI* for all possible collection and treatment percentages at four different hypothetical reuse rates ( $z = 10, 40, 70$  and  $100\%$ ). Low values can be reached with an unlimited number of combinations of  $x$ ,  $y$ , and  $z$  (collection, treatment, and reuse rates, respectively). Higher values of *WRI* can be reached only through higher rates of collection, treatment, and reuse, as these three factors are of equal importance in Equation 8.

In many MENA countries, the total collection rate through sewerage networks and on-site systems exceeds  $90\%$ , except in a few where it is around half this rate (Table 2). Table 3 compares the *WRI* in some selected MENA countries. Israel has reached a high collection rate of about  $95\%$  with  $68\%$  treatment of the collected wastewater and  $83\%$  reuse of the treated flow<sup>21</sup>, thus, with a *WRI* of  $53.7\%$ . Potentially, Israel can increase its *WRI* to  $95\%$  by increasing the treatment from  $68\%$  to  $100\%$  and reuse from  $83\%$  to  $100\%$ , assuming that the production and collection rates are unchanged. If Israel reuses all of its currently treated wastewater, its *WRI* will reach about  $65\%$ . High *WRI* values can be reached if the treatment and reuse rates are increased to a level closer to that of collection. For example, Jordan, Tunisia, and Saudi Arabia, respectively, could reach a *WRI* of  $99\%$ ,  $80\%$ , and  $100\%$  if all their collected wastewater is treated and reused; Saudi Arabia currently is lagging behind whereas Tunisia and Jordan take a middle position, and Israel is achieving slightly above half of its potential (Table 3). All these countries have high collection rates but need to increase their treatment and reuse efficiencies in order to reach such high *WRI* values. This can be achieved by constructing treatment plants and by encouraging on-site management of wastewater at household and community levels in peri-urban and rural areas.

As mentioned previously, most countries of the region have reasonably high rates of wastewater collection, which is driven by urbanization, public health, and environmental incentives. Thus, the low *WRI* values and the imbalance (failure) in the reclaimed-wastewater market are mainly due to low rates of wastewater treatment and/or reuse. For reuse, however, disincentives tend to be stronger than incentives because reuse offers direct benefit to a lower number of groups only, i.e., farmers and water resource managers.

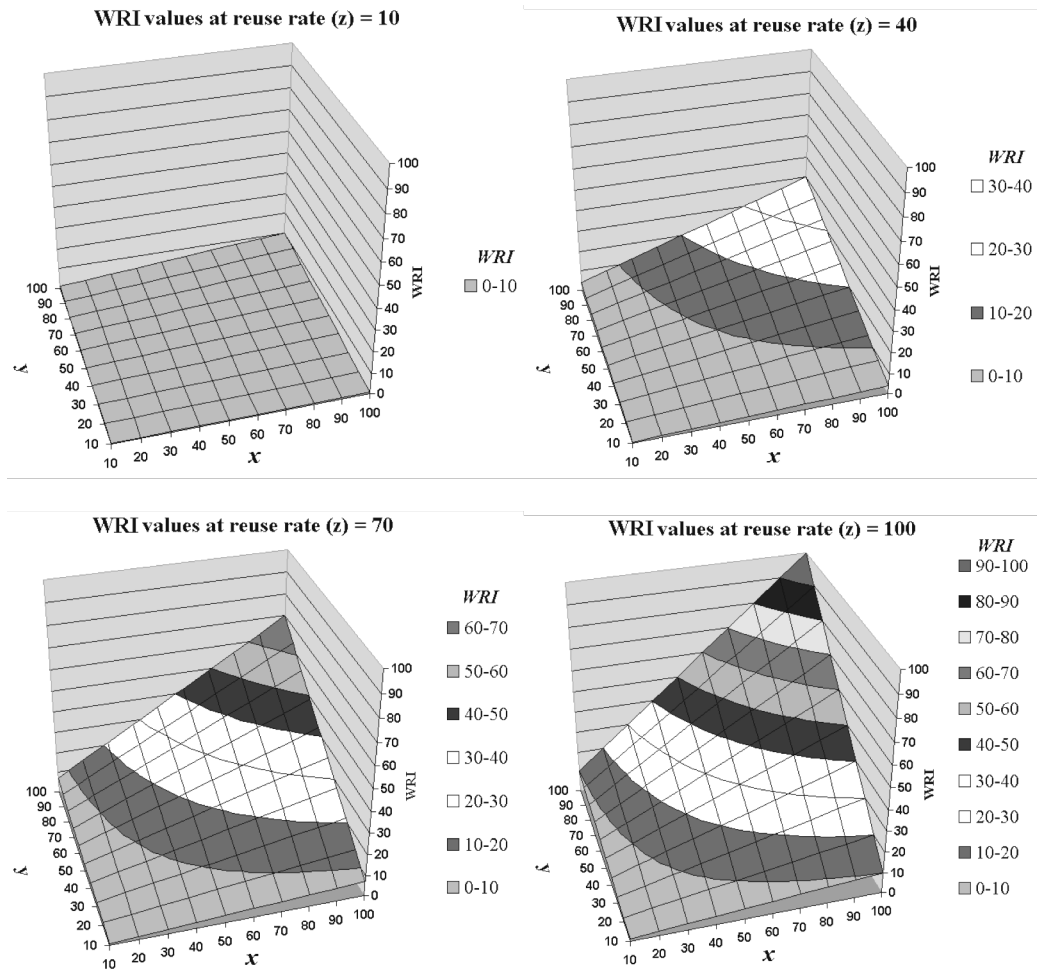


Figure 3: Graphical representation of the *WRI* at reuse rates of 10, 40, 70, and 100%, respectively.

Table 3: *WRI* in selected MENA countries (flow rates per annum).<sup>21, 40, 41, 42</sup>

Country	<i>G</i> (million m <sup>3</sup> )	<i>C</i> (million m <sup>3</sup> )	<i>T</i> (million m <sup>3</sup> )	<i>R</i> (million m <sup>3</sup> )	$x = C/G$ (%)	$y = T/C$ (%)	$z = R/T$ (%)	<i>WRI</i> (%)
Israel	464	440	300	249	95	68.2	83.0	53.7
Jordan	241	239	80	67	99	33.5	83.8	27.8
Tunisia	395	316	148	50	80	46.8	33.8	12.7
Saudi Arabia	1,347	1,347	292	92	100	21.7	31.5	6.8

G: generation; C: collection; T: treatment; R: reuse; *WRI*: Wastewater Reuse Index.

A large number of factors have to be analyzed for each component of the *WRI* in order to ensure better utilization of wastewater as a non-conventional resource of water. Increasing *WRI* in the

<sup>40</sup> ONAS. (2001). Annual report of the National Agency for Sewerage. Tunisia.

<sup>41</sup> MWI. (1999). Annual report of the Ministry of Water and Irrigation. Amman.

<sup>42</sup> Abu Rizaiza, O. (1999). Modification of the standards of wastewater reuse in Saudi Arabia. *Wat. Res.*, **33**(11): 2601-2608.

MENA region requires increasing the reuse rates. Extensive reuse of reclaimed wastewater in the region is constrained by a number of barriers. Based on authors' experience, the most important barriers and foreseen solutions are explained as follows:

- (i) The MENA countries adopt supply-driven approach in which the concern for reuse of reclaimed wastewater is often subsequent to design and implementation of treatment plants. For example, Tunisia started to explore wastewater reuse after the implementation of many treatment plants for environmental considerations along the sea coast that is faraway from agricultural lands. The MENA countries are recommended to adopt a demand-driven approach when implementing new wastewater treatment plants. In other words, the end use of reclaimed wastewater should decide the effluent quality, technology, and location of treatment plants.
- (ii) The freshwater tariffs for agricultural irrigation are very low compared to the domestic water tariffs. Therefore, farmers are not attracted to replace freshwater with reclaimed wastewater. The MENA countries are recommended to restructure their water and wastewater pricing strategies with increasing the gap between freshwater and reclaimed wastewater tariffs. This, on one hand, would reduce agricultural water demand, and on the other hand, it would make irrigation with reclaimed wastewater more economically attractive than that with freshwater.
- (iii) Farmers and common public of the MENA countries have limited knowledge and unclear perceptions towards wastewater reuse and the prevailing water shortage. Many people believe that Islamic religion prohibits reuse of treated wastewater. On the contrary, Islamic religion supports water demand initiatives as well as reuse of treated wastewater that does not have negative impacts on public health. Joint efforts are needed from governmental, non-governmental, academic, and aid institutions on developing appropriate educational and awareness programs and initiatives that improve public knowledge and perceptions.
- (iv) All countries adopt stringent guidelines and standards for wastewater treatment and reuse with over concern for public health and environmental protection. Complying with such standards implies construction of sophisticated and costly wastewater treatment plants. The MENA countries are recommended to adopt more flexible standards without compromising public health and environmental protection. For example, irrigation of



fodder crops and trees does not require high quality water which can be produced by modest wastewater treatment systems.

- (v) Most countries lack for adequate storage facilities to cope with continuous production of treated wastewater and seasonal variations in irrigation water demand. Without large storage reservoirs, substantial amounts of treated wastewater will have to be discharged into the environment without utilization during off-irrigation periods. At the same time, the amounts of treated wastewater available to farmers will not satisfy the irrigation water needs. Therefore, success of any wastewater reuse scheme necessitates having storage facilities for the treated effluent.

## **Conclusions and recommendations**

The Middle East and North Africa Region suffers from a chronic water shortage that threatens its political stability and sustainable development. The reuse of reclaimed wastewater is recognized by all experts and policy-makers of the region as an important non-conventional water resource. This paper considers reclaimed wastewater as a commodity whose market is unbalanced; growing supply -demonstrated by high rates of wastewater generation and collection, and medium rates of treatment- against a stagnant demand -demonstrated by low rates of wastewater reuse and the large proportions of treated wastewater that are discharged into the water bodies. The high rates of collection are driven by urbanization, health, and environmental incentives. Thus, augmenting freshwater availability in region implies improving wastewater utilization and balancing the reclaimed-wastewater market through maximizing the rates of wastewater treatment and reuse.

The currently-used indicators to semi-quantify achievements in wastewater reuse are misleading as they account for only the reused amounts of wastewater from urban treatment plants and omit to include that from rural communities. They do not enable valid comparisons between and within countries. This paper suggests a yardstick indicator that is more inclusive and takes into account the contribution of each component in a wastewater utilization scheme: collection, treatment, and reuse. This indicator is called Wastewater Reuse Index (WRI) which quantifies reuse as a percentage of the total generation of wastewater. In the MENA region, Saudi Arabia has a low WRI, while Tunisia and Jordan have a medium WRI. Although Israel has the highest WRI, it is still only half of its potential.

Increasing WRI in the MENA region requires extensive reuse of reclaimed wastewater, which is constrained by a number of barriers. Based on authors' experience, the most important barriers and foreseen solutions are summarized as follows:

1. The reuse of reclaimed wastewater is often recognized after the design and implementation of treatment plants. The MENA countries are recommended to adopt a demand-driven approach in which the end use of reclaimed wastewater decides the effluent quality, technology, and location of treatment plants.
2. Due to low tariffs of irrigation water, farmers are not attracted to replace freshwater with reclaimed wastewater. The MENA countries are recommended to increase the gap between freshwater and reclaimed wastewater tariffs in order to make irrigation with reclaimed wastewater more economically attractive than that with freshwater.
3. Farmers and common public of the MENA countries have limited knowledge and unclear perceptions towards wastewater reuse and the prevailing water shortage. Extensive efforts are needed on developing appropriate educational and awareness programs and initiatives that improve public knowledge and perceptions.
4. The MENA countries adopt stringent guidelines and standards for wastewater treatment and reuse with over concern for public health and environmental protection. Complying with such standards implies construction of sophisticated and costly wastewater treatment plants. The MENA countries are recommended to adopt more flexible standards without compromising public health and environmental protection.
5. Most countries lack for adequate storage facilities to cope with continuous production of treated wastewater and seasonal variations in irrigation water demand. Therefore, success of any wastewater reuse scheme necessitates having storage facilities for the treated effluent.

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